Cosmic Chemistry: Planetary Diversity

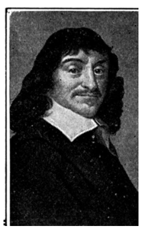
Are We Related? Looking for Patterns In Planetary Diversity

TEACHER GUIDE

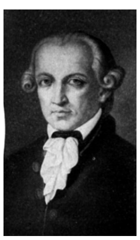
BACKGROUND INFORMATION

From the beginning of scientific endeavor, scientists have looked for patterns in unorganized and isolated observational data. The Genesis module, *Cosmic Chemistry: An Elemental Question*, focused on Mendeleev's pursuit of order from his observations of the properties of known chemical elements. The *Cosmic Chemistry: The Sun and Solar Wind* module was based on an almost universally-accepted standard solar model, which was developed as information was collected over time.

A standard model for the solar system formation is one of the major unsolved problems of modern science. Rene Descartes advanced ideas concerning the condensation of the sun and planets from a chaotic mass of gas and dust as early as the 1300s.



In 1755, the German philosopher Immanuel Kant proposed that a rotating nebula, a cloud of gas and dust, might have condensed to form the sun and planets, with the planets moving in the same direction as the rotation of the original nebula.



The French mathematician, Pierre Simon de Laplace, extended and refined Kant's "nebular hypothesis" in the 18th century. Laplace calculated the increase in rotation of the contracting nebula and adding the notion that rings of material might have spun off from the nebula by centrifugal action, each ring forming a planet moving in a nearly circular orbit.

The "Laplacian hypothesis" was generally accepted until 1900, when University of Chicago geologist T. C. Chamberlin and astronomer F. R. Moulton, proposed that the angular momentum of material that later formed the planets was furnished by an intruder star passing quite close to the sun. The Chamberlin-Moulton theory was designed to explain the solar system's uniqueness in terms of a possible but highly unlikely event.

At this time, unfortunately, no one model satisfactorily explains everything that has been observed. Neither can the information that is currently being gathered by terrestrial and space-probe instrumentation be adequately explained by one current model. Interpreting the overwhelming collection of data from terrestrial observation and interplanetary space probes is proving to be a challenge for even the most dedicated planetary scientists.

Because we cannot directly observe the planetary system "up close and personal" from the Earth, many interpretations regarding the planets based on terrestrial observations have proved to be incorrect. Most of these conclusions were the result of fragmented data analogous to that of the blind men describing an elephant.* Our observations were also impaired, not only by the Earth's atmospheric filter, but, in some cases, by the atmosphere of the observed planetary body.

*The legend tells of blind men describing an elephant differently because they were examining different parts of the animal without being able to "see" the whole animal. One man said the elephant was like a tree because he was feeling its leg; another thought it was shaped like a fan because he was touching the ear; still another, holding the tail, said the elephant resembled a rope. Those examining the trunk, tusks and body described the elephant as a long flexible tube, a spear, and a wall.

As is the case in many scientific endeavors, new pieces of information often do not fit, causing us to rethink not only our organizational patterns but also our current theories and models.

The background information in "So, Mr. Holmes, What Is the Problem???" can be used, either as a student handout or for a classroom presentation, to introduce your students to the complicated scientific problems involved in studying planetary diversity.

Ultimately, the correct theories for the origins of the diverse objects in our solar system, including planetary atmospheres, will be validated by their predictions of chemical and isotopic compositions relative to the average nebular composition preserved in the surface layers of the sun. The Genesis mission is designed to provide solar abundances at the precision required in order to test these theories. (See Figures 1 and 2 and Table 1 in the Student Text, "Solar Nebula Supermarket.") Moreover, Genesis will test fundamental assumptions, such as whether or not solar and nebular compositions were identical.

In the Student Activity, "Are We Related?," students will be using measurements (and results of calculations involving these measurements) regarding the planets' physical and chemical characteristics. They will start with some of the *most universally accepted* planetary data, including, for example: planetary distances from the sun, equatorial diameters, rotational periods, masses, and average temperatures.

You will note, and should encourage your students to note, that the sources used for the data in this activity have been referenced. These sources were chosen not only because they were published recently, but also because they incorporated current information from space-probe instrumentation.

Students will also be working with information that is often presented as known facts when, indeed, those "facts" may be conclusions based on limited basic data. Included in this category are properties such as planetary densities, components of their internal structures and their atmospheric makeup. Not all of these properties can be observed directly, even those of the Earth. They are, therefore, *inferred* from data that, although compelling, probably does not present the whole picture. (See similar situation in the first activity of the Genesis module, *Cosmic Chemistry: An Elemental Question*.)

For this reason, there are many possible and plausible interpretations of these data. Students should be encouraged to look for their own methods of grouping or "patterning." There are many good answers and the more variation in the patterns found, the more interesting the feedback sessions will be as students defend their patterns in answering these questions:

1. It has been presumed that the nine planets, among other highly diverse objects of our solar system, originated from condensation of a relatively homogeneous solar nebula.
   a) What evidence do you find that supports this theory?
   b) Are there any specific data given in the activity that do not appear to be explained by this theory?
   c) What other information would be helpful in making your decision?

2. There was recently another effort made to remove Pluto from the list of planets and to reduce its classification to that of a "Trans-Neptunian Object" or a minor planet. The controversy is not a new one, having been raised in 1950 and again in 1987. What evidence do you find that either supports Pluto being classified as a planet or something other than a planet?

Use the material in Appendix A and Appendix B to refresh and/or expand your own background in the history of planetary science. You can also review descriptions of the planetary structure and evolutionary models. Make print copies or have students access the electronic version of any materials that you wish.

NATIONAL SCIENCE STANDARDS ADDRESSED

Grades 5-8

Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Physical Science
- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy
- Interactions of matter and energy

Science and Technology
- Understandings about science and technology

History and Nature of Science
- Science as a human endeavor
- Nature of science and scientific knowledge
- History of science and historical perspectives

Grades 9-12

Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Earth and Space Science
- Earth in the solar system
- The origin and evolutions of the Earth system
- The origin and evolution of the universe
- Energy in the Earth system
- Geochemical cycles

Physical Science
- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy
- Interactions of matter and energy

Science and Technology
- Understandings about science and technology

History and Nature of Science
- Science as a human endeavor
- Nature of science and scientific knowledge
- History of science and historical perspectives

(View a full text of the National Science Education Standards.)

MATERIALS

For each student
- Copy of Student Activity, "Are We Related?"
- Copy of Student Data Sheet, "Are We Related?"
- Copy of Student Text, "So, Mr. Holmes, What Is the Problem???"
- Copy of Student Text, "Solar Nebula Supermarket"
- Copy of Appendix A, "The Solar System or Do Nine Planets a Baseball Team Make?"

For each group:
- Newsprint or poster board and colored markers to display groupings and patterns from data

Alternate Strategy Tip

One strategy for this lesson is to have the class work in groups of four. Then the teacher could "jigsaw" the groups such that each of the four students in the home group join a different expert group that will look at two data tables, answer the questions, and then return to the home group and share the information learned and complete the poster activity.

Optional for the classroom:

- Rock and mineral samples, including those shown as part of the internal structures of planets—iron ores (iron oxide, iron sulfide, iron pyrite), basalt, granite, olivine: quartz (silicon dioxide), feldspar and mica, the latter two of which are aluminum silicates
- Periodic table

PROCEDURE

1. Before class make copies of the following handouts:
   Student Activity, "Are We Related?"
   Student Data Sheet, "Are We Related?"
   Student Text, "So, Mr. Holmes, What Is the Problem???" (See Procedure 2 below.)
   Student Text, "Solar Nebula Supermarket"
   Appendix A, "The Solar System or Do Nine Planets a Baseball Team Make?"

2. Either distribute copies of "So, Mr. Holmes, What Is the Problem???" or use the information in it to "set the stage" for this *Planetary Diversity* module.

3. Distribute copies of Part 1 of the Student Activity, "Are We Related?" to each student. This includes assignments #1 through #7.

4. Divide the class into groups of three or four students. Each group should designate a leader, recorder, and one or two researchers.

5. After the team members have read the "Background Information" on the first page of the Student Activity, "Are We Related?" have the team leaders ask the other team members whether or not they understand the assignment. If there are questions, the team leader should ask you for clarification.

6. Post the due date for the assignment somewhere in the room and call students' attention to it. There is ample data given in the activity to warrant a minimum of two class periods for identifying patterns or groupings and another for designing students' displays.

7. Have copies of Part 2 of the student activity and other handouts available for the team leaders as they request them.

8. Be available to answer questions as they arise. Some of the questions that were asked during the classroom pre-tests are found in the "Information Tips" box. It is best if you wait until students ask for this kind of information before giving it.

Information Tips

1. **What does AU mean?** AU stands for astronomical unit, the mean distance from the Earth to the sun, which is 149.6 million kilometers.
2. **What does it mean when it says "Earth = 1"?** This means that the value of that measurement for all the other planets has been divided by the Earth's value of that measurement, forming number ratios that are easily compared.
3. **Why are the diameters of the planets labeled "of the equators"?** Because most planets are not truly spherical; they tend to be flattened at the poles.
4. **What is the difference between a "mantle" and an "envelope"?** Mantles have more well-defined boundaries than envelopes.
5. **Why are the Internal Structure diagrams circular if planets are not really spherical?** These diagrams are drawn to scale based on equatorial diameters. In a scale this small, the "flatness" is not significant.
6. **What does "retrograde rotation" mean?** It means that a planet rotates on its own axis in a direction opposite to that of most other planets. The sun rises in the west and sets in the east. (Venus is an example of a a planet that has retrograde rotation.)
7. **What does "average" density mean?** Most, if not all, planets are "layered," with each layer being made of components of different densities. The average density of a planet is based on its total mass, determined indirectly by the strength of its gravitational pull, divided by its total volume.
8. **Define the terms, basalt, olivine, and granite**. Basalt is a dark, heavy rock of volcanic origin; olivine is $(MgFe)_2SiO_4$, a mineral constituent of igneous rocks; and granite is a hard igneous rock made of quartz (silicon dioxide), and aluminum silicates—feldspar and mica.

9. Designate a location for posting the groups' patterns and grouping displays.

10. During the Part 1 follow-up session:
    a) Allow time for each team to make their oral presentations.
    b) Ask students to make generalizations as they study individual teams' findings.

Ask: *What made it so difficult to find groups or patterns in the data given?*

11. Distribute copies of Part 2 of the Student Activity, "Are We Related?" to each student. This includes assignments # 8 through #10, which may be done on an individual or group basis. Assign a due date for the completion of this assignment.

12. During the follow-up session for Part 2 of this activity, ask questions similar to the following:
    a) On what basis did you make your decisions regarding:
        1) The groupings of planets as either terrestrial and Jovian?
        2) The validity of the solar nebular condensation theory of planetary formation?
        3) The data given that did not appear to be explained by the condensation theory?
        4) The reclassification of Pluto?
    b) What problems do you find with the condensation model?
    c) What other information would you need in order to decide whether or not the condensation model is valid?
    d) If your students have worked on either of the previous Genesis Cosmic Chemistry modules—*An Elemental Question* or *The Sun and Solar Wind*—ask them how the information given in Figures 1 and 2 and/or Table 1 in the student text might relate to these previous Genesis modules.

Alternate Strategy Tips

Have rock and mineral samples available for students to examine during the time they are studying the internal structures of the planets.

Have a periodic table wall chart available for students to note the location of the elements present in the sun and solar nebula.

Some Fun Stuff!
If students have difficulty remembering the order of the planets with respect to the sun, try these mnemonic devices, or, have them design their own!
<u>M</u>ay's <u>V</u>iolet <u>E</u>yes <u>M</u>ake <u>J</u>ohn <u>S</u>it <u>U</u>p <u>N</u>ights <u>P</u>ondering or
<u>M</u>y <u>V</u>ery <u>E</u>mpty <u>M</u>outh <u>J</u>ust <u>S</u>wallowed <u>U</u>p <u>N</u>inety <u>P</u>eanuts
- from Larry D. Kirkpatrick, The Physics Teacher, <u>30,</u> 25 (1992).

A Planet Rap Song, contributed by Thomas Arny, can be found in the Physics Teacher, <u>30,</u> 186 (1992).

For Further Inquiry

If you have students who are mathematically oriented, you may pose the following question as a follow-up to this activity:

Although there have been a number of theories to explain the origins of the planets, the problem of what mechanism determined the location of planetary orbits around the sun and the location of the orbits of satellites around the planets has not been resolved. Before Neptune and Pluto were discovered, the German astronomers Titius and Bode noted a seeming regularity in the spacing of the planets. Note that in Data Table 2, the distances of the planets from the sun are given in AU's. These numbers can also be calculated from a formula, planet's distance from sun in AU's = $\frac{(x+4)}{10}$ where x is the number in a series of 0, 3, 6, 12, 24.... Note that each number, starting with 6, is twice the preceding number. An alternate expression of this law is: planet's distance from sun in AU's = $0.4 + 0.3 \times 2^n$, where $n = -\infty$ for Mercury, 0 for Venus and is increased by 1 for each successive planet.

Use one of these Titius-Bode formulae to determine:
a) Which planets' distances do not follow this rule?
b) What solar system phenomenon is found between the inner and outer planets where the Titius-Bode rule predicts a planet where there is none?
c) The significance, if any, of these mathematical statements regarding the location of planetary orbits around the sun?*
d) Which planets' satellites obey the Titius-Bode law?

Notes to instructors: Students will have to research which planets have satellites and the satellites' spatial location with respect to the planet in order to answer question d. That information is not a part of this module.

*The answer to c) is: recent calculations show that this law reflects a coincidence rather than a general physical property.